Techno-Economic Analysis for the Role of Single End Energy User in Mitigating GHG Emission

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Abstract

Background

End energy user relies on fossil fuel-based national grid to meet their energy demand; hence, indirectly contributing towards greenhouse gases (GHG) emission and causing climate change. This study aims to investigate the minute role of a single, end energy user in GHG mitigation by shifting to the green renewable energy source, photovoltaics (PV) through its techno-economic analysis.

Method

For the study impact, NASA Meteorological Data is used to select an ideal single energy user equipped with 10 kW PV system based on annual- average daily solar radiations and temperature through MATLAB/Simulink, among eleven populous cities of Pakistan. Helioscope software is used to select tilt and azimuthal angle to expose PV surface for most of the solar radiations. Afterwards, RETScreen software is used for cost, financial and GHG analysis.

Results and Conclusion

The proposed system at single end energy user mitigates 6.9 tonnes of CO_2 per annum while producing 16,832 kWh per annum and recovering its 7337$ capital cost in less than five years in the project's 25-year life span. A single energy user invisible to national grid can play a pivotal role in GHG mitigations while earning from its investment and achieving energy independency from the main grid at the same time.

1. Introduction

Energy serves as the backbone of the modern era, while developing countries face severe energy shortages [1]. On the contrary, across the globe, there is another movement with growing concern over energy production through conventional energy resources in context of global climate change [2] like, in Pakistan, a major energy share is of conventional energy resources [3–4]. Moreover, research analysis suggests increment of 2.9% and 2.0% in energy consumptions and carbon emissions, respectively, in 2018 [5]. Conventional energy production involves emissions of nitrous oxide (N_2O), methane (CH_4) and water vapours (H_2O) apart from carbon dioxide (CO_2) emissions. These greenhouse gases (GHG) blocks the re-emitted radiation from the Earth initially received by Sun, trapping the energy, hence raising the Earth temperature, cause of climate change [6–7]. In response, the world is implementing the solutions to reduce this cause without any change in demand and supply i.e. electric grids transformation from conventional energy resources to green renewable energy resources has moved due to environmental concerns [8]. Global efforts include Paris Climate Accord [9], Kyoto protocol [10] and European Union targets- 2020, 2030 & 2050 [11–13] as its important conventions and energy/emission targets. This serves as the cause of investigation and aim of this paper to present the PV system feasibility for greenhouse gases mitigation at a single, end energy user. Moreover, careful selection of the best location for 10 kW PV system installation among eleven densely populated cities of Pakistan through Simulink based on daily solar radiation and ambient temperature, data retrieved from NASA Meteorological Data. In addition, the selection of optimal PV plant installation parameters to avoid efficiency drop through Helioscope software. Finally, RETScreen is used to analyze the degree of relief from high electricity pricing to end energy user in the project's 25 life-year span. For this purpose, cost analysis and financial analysis is carried out. Moreover, user shift from main grid (MG) to PV system for its energy demand relaxes MG and supports GHG emission mitigation at his individual level. Proposed system is reflected in the form of the flow diagram in Fig. 1.

In south Asia, a developing country Pakistan is facing energy shortage problems since its birth, and in 2017 from 5 giga watt to 7 giga watt [14]. Pakistan energy sector is still burdened with circular debts [15]. The world is moving to green energy resources while Pakistan's major share of energy is from conventional energy resources [3–4] and over these conventional energy resources which involves GHG emissions and climatic concerns are discussed in literature as her energy analysis with their role in CO_2 emission [16]. However, because of Pakistan's unique geographical coordinates and seasonal pattern variations, it is ideal for green renewable energy production such as solar PVs and wind power plants. Pakistan's mean solar irradiation is 5-7kWh/m2 in a day and on the average sun shines for 8–10 hours/day for over and above 300 days in a year [17–18]. According to a careful estimation by Alternative Energy Development Board (AEDB) Pakistan contains 2900 GW solar potential [19]. This offers Pakistan with a

tremendous possible solution to address its energy issues by green renewable energy resources in a timely manner to address its two major challenges at the same time. Conventional energy resources are not only expensive, but fluctuations in oil prices burden the country's imports. With the increase in population, energy consumption has experienced an increase in the household share of 35–46.5% in last two decades, and the expected increase in energy demand will be 113 GW by 2030 with 8% annual growth rate [3, 20, 21]. Across the globe, developing countries and developed countries have initiated incentives-based support programs for faster penetration of green renewable energy sources i.e. distributed solar photovoltaic (PV) generation. Moreover, net-metering has been successfully implemented by Denmark, Belgium, Australia, USA, China, Brazil, Bangladesh, India, etc., for rapid market expansion of solar PVs [20]. In Pakistan, grid-tied residential PV generation systems installations are very slow; despite higher solar-irradiation, enactment of Net-metering by government and a significant decrease in solar PV module prices [20]. Renewable based energy generation will not only guarantee uninterrupted power supply but will also help to reduce the GHG emissions in broader ways.

The quantity of electricity produced at any location depends on the largest extent on the solar irradiation on the location [7]. However, the output of PV module linearly depends upon temperature as well; an increase in temperature causes efficiency loss, hence a decrease in PV output [22]. Literature suggests that the grid-connected solar PV systems are more feasible, reliable and economical than standalone systems [23]. And for the deployment of solar power plants, there is a need for techno-economic and environmental feasibility analysis, prior to making investment decisions [24]. For this purpose, a relatively easy and user-friendly software package to analyse various types of Renewable-energy and Energy-efficient Technologies inculcating PV systems, RETScreen is used. It is developed by Canada for multiple analysis such as energy, feasibility, emission, financial and risk assessment, [25]. In literature, multiple studies are considered in RETScreen which provided valuable information of environmental assessment, emission assessment, feasibility assessment, technical assessment, economic assessment comprising of cost and financial assessments of mega projects in multiple countries across the globe. For instance, Nigeria's 100 MW proposed PV system is assessed in country's twenty-five location for financial (profit) assessment and its relative GHG emissions mitigation effectiveness[7], Bangladesh's 1 MW grid-connected PV system's financial viability in fourteen regions of the country [26], Chile's 30 MW PV plant's financial/sensitivity assessment at twenty-two locations of the country [27] Iran's 100 kW grid tied-PV system for economic assessment [28] and Pakistan's 10 MW PV system economic viability at eight sites of the country[3]. Literature provides an assessment of multiple regions of land-based on RETScreen.

1.1 Literature Analysis and Proposed System Novelty

Table 1. compares the proposed approach with related PV system studies, specifically carried out in RETScreen software. Literature is majorly focused on megawatt projects and minute role of single, end energy user, which is fed from conventional energy-based national grid is overlooked.

In literature, the best location for the installation of PV system is either decided by only a single parameter; average daily solar radiation or after all locations detail analysis. Proposed study uses relation of annual average daily solar radiation and temperature with PV system output in MATLAB/Simulink software for best location selection for detail analysis. Selection of tilt and azimuthal angle in literature is either selected to a fixed value or locational latitude but proposed study used advance solar design software, Helioscope for best-fit tilt and azimuthal angles. All analysis is carried out in RETScreen software.

Table 1
Comparison of Proposed Approach with Related Studies

Literature	Sun Tracking Mode	Size of PV System	Locations	Geographical Location Data Source	Location Selection Tool	Location Selection Parameter	PV Plant tilt and azimuthal angle selection	Analysis
Proposed Approach	Fixed	10 kW, Single end energy user system	11	NASA	MATLAB/ Simulink	Annual average daily solar radiation and temperature	Helioscope	Cost, financial and GHG
[3]	Single Axis	10 MW, Power Plant	8	NASA	RET Screen	Annual average daily solar radiation	Tilt angle: Location's latitude	Financial and Sensitivity
[7]	Fixed	100 MW Power Plant	25	NASA	All locations	Average daily solar radiation	-	Cost, financial and GHG
[26]	Fixed	1 MW Power Plant	14	Geospatial Toolkit and NASA Surface Meteorology and Solar Energy	All locations	Average daily solar radiation	Tilt angle: Locations latitude and Azimuthal angle zero	Economic/financial GHG
[27]	Dual Axis	30 MW Power Plant	22	NASA	All locations	Average daily solar radiation	-	Financial, cost, risk, sensitivity and GHG
[29]	Fixed	6 MW Power Plant	6 states	NASA	All States	Daily solar radiations	Tilt angle 15 fixed	Financial, GHG, sensitivity and risk
[30]	Fixed	5 MW Power Plant	24	NASA	All Locations	Average daily solar radiations and grid accessibility	Tilt angle: Locations latitude (South) and Azimuthal angle zero	Financial and GHG
[31]	One Axis	10 MW Power Plant	1	NASA and Solar Energy Database of proposed location	Single Location	-	Azimuth angle zero	Cost, Financial, Sensitivity and GHG

2. Methodology

PV system feasibility and emission assessment at end energy user, a small part of the energy paradigm are necessary. End energy user consumes the energy but in case of PV system equipped home, trades surplus energy to the main grid. Surplus energy supplied by the user is not visible/monitored by the national control centre. However, it provides relaxation to the national grid in peak shaving, grid stabilization, lessening the dependence on conventional sources and importantly, end energy user small but significant role against environmental concerns. Therefore, the proposed PV system is on-grid system means no backup battery system involves. PV systems running cost as well as emission (CO_2 and H_2O etc.) are zero.

2.1. Location Selection

Pakistan's eleven geographical sites; Peshawar, Multi Gardens (Wah), Multan, Lahore, Rawalpindi, Sargodha, Faisalabad, Bahawalpur, Bannu, D.I. Khan and Jhang, geographical data is provided by RETScreen, provided in Table 2. RETScreen utilizes meteorological data for any specific location from its meteorological data inventory provided by NASA [25]. MATLAB/Simulink is used for best location selection at energy user based on two important parameters, affecting the output most; daily solar radiation and ambient air temperature [7, 22] Simulink PV module parameters to verify the maximum possible power at each of eleven locations through daily solar radiation and temperature is provided in Table 3. A DC load is connected at PV output for the measurement of possible power output, a ramp load starting from 0 to 21.1.

Table 2
Average Daily Solar Radiation and Air Temperature of Eleven Pakistan's geographical Locations

Location	**Air Temperature (Celsius)**	**Daily solar radiation e horizontal ($kWh/m^2/d$)**	**Latitude**	**Longitude**	**Elevation (meters)**	**Power Output (Watt)**
Peshawar	22.7	5.16	334	71.5	345	241
Multi Gardens (Wah)	22.8	5.19	33.8	72.8	502	242
Multan	25.3	5.09	30.2	71.5	125	236
Lahore	24.4	4.68	31.6	74.3	220	225
Rawalpindi	21.6	4.02	33.6	73	508	206
Sargodha	25.6	5.10	32.1	72.7	274	236
Faisalabad	26.6	5.03	31.4	73.1	18	232
Bahawalpur	27.9	5.13	29.4	71.7	117	234.5
Bannu	23.7	4.97	33	70.6	542	234
D.I. Khan	26.1	4.86	31.8	70.9	255	228
Jhang	26.8	5.02	31.3	72.3	160	231.5

Table 3
Simulink PV Module Parameters for Location Selection

Parameters	**Values**
Max Power	59.85 W
Open Circuit Voltage	21.1 V
Short Circuit Current	3.8 A
Voltage at maximum power point (Vmp)	17.1 V
Current at maximum power point (Imp)	3.5 A
Temperature coefficient of Voc (%deg C)	-0.38
Temperature coefficient of Isc (%deg C)	0.065

Careful analysis of results favours Multi Gardens with Wah Climatic Data with 242 W productions in the presence of 5.19 kWh/m^2 daily solar radiation with 22.7 Celsius air temperature. Rawalpindi, results showed that its power output is lowest among all, 206 Watts in the presence of 4.02 kWh/m^2 daily solar radiation with 21.6 Celsius air temperature. Based on Simulink results, Multi-Gardens location is best for detail analysis of 10 kW PV system for single end energy user role in GHG mitigations.

2.2. Parameters Selection

NASA's complete meteorological data for proposed 10 kW PV system at Multi Gardens is provided in Table 4. It provides valuable data of multiple key factors like daily solar radiation-horizontal, air and Earth temperature, relative humidity, wind speed and atmospheric

pressure over a whole year. Figure 2. reflects values of daily solar radiation-horizontal surface and air temperature factors at 5.19 kWh/m^2/d and 22.8 Celsius for a whole year, respectively. These two factors play pivotal roles in PV systems output [32].

Table 4
The climate data of Multi Gardens, Pakistan

Month	Daily solar radiation e horizontal (kWh/m^2/d)	Air Temperature (Celsius)	Earth Temperature (Celsius)	Relative humidity	Wind speed (meter/second)	Atmospheric pressure (kilo Pascal)
January	3.19	10.5	8.4	45.1	2.0	95.0
February	3.92	12.5	11.2	49.0	2.2	94.8
March	4.87	17.8	17.0	46.0	2.3	94.6
April	6.22	23.8	23.6	38.7	2.4	94.3
May	7.16	30.3	31.0	25.5	2.4	93.8
June	7.43	34.2	35.7	25.0	2.3	93.4
July	6.48	32.5	34.1	46.7	2.3	93.3
August	5.75	30.2	31.2	57.4	2.2	93.6
September	5.51	27.9	28.0	48.1	1.9	94.0
October	4.93	23.1	21.8	33.9	2.0	94.5
November	3.84	17.5	15.3	30.9	2.0	94.9
December	2.97	12.8	10.2	37.3	1.9	95.0
Annual	5.19	22.8	22.3	40.3	2.1	94.3

For a realistic assessment of the proposed 10 kW PV system at Multi Gardens, RETScreen must be provided with real project values, and these values were provided by technical workers working in the same energy domain. Multi-Gardens location has considerable dust pollution due to its vicinity to crushing machines, which can significantly affect PV system output. A value of 12% was chosen for PV array losses as miscellaneous losses. Since, azimuthal and tilt angle ensures the maximum extraction of energy from solar radiations, Helioscope, an advanced solar design software is utilized. Helioscope is used by the solar companies for the designing, engineering and selling solar arrays [33]. Since grid operates on 50 Hz alternating current, an inverter is required to invert DC to AC, which has losses involve in it as well. A modern, efficient inverter is considered with 98% efficiency. Plant data, PV system electrical specifications and main inverter data is provided in Table 5, Table 6 and Table 7.

Table 5
Technical specifications of on-grid photovoltaic system

Plant capacity	10 kW
PV module	Mono-si-SPR-X21-335-BLK
Tracking mode	Fixed
Tilt Angle	-18.4 [33]
Miscellaneous PV array losses	12%
Azimuth	180 [33]

Table 6
Electrical Data of PV module

Power (nominal)	335 W
Efficiency	19.9%
Open-circuit Voltage	44.8 V
Short-circuit Current	9.51 A
Power temperature Coefficient	-0.37%/Celsius

Table 7
Inverter specifications

MPPT Tracker	Enabled
AC nominal output	10,000 W
Frequency	50 Hz
Max. efficiency	98.0%

3. Result Analyses

3.1. Cost Analysis

Capital cost analysis is required for the user in order to match it with his purchasing power. This cost analysis provides initial detail investment plan of the proposed 10 kW system at the best location, Multi Gardens. Cost analysis provides a complete knowledge of investment divided into the feasibility study, engineering cost, PV system cost, inverter costs and miscellaneous costs, which are 93$, 360$, 4924$ and 1959$, respectively. Table 8. Provides data for proposed 10 kW PV system after market survey of PV system and from same field experts. RETScreen offers the right place to carry out either detail or short cost analysis. RETScreen detail analysis is used for this cost study.

Table 8
Percentage distribution of capital cost for proposed 10 kW

Initial Cost	Feasibility Study	1.3%
	Engineering	4.9%
	Power system	67.1%
	Inverter and Miscellaneous	26.7%
	Total	100%

Feasibility study gives insights about site investigation, resource assessment, environmental assessment, detail cost estimate and report preparation. Engineering study about mechanical design, electrical design and civil structural support design. These are soft study. On the contrary, power system study asks input regarding photovoltaic-10 kW cost and its distribution box for net metering. Finally, inverter and miscellaneous analysis are about inverter cost, installation cost, training and commissioning. These are broadly referred to as hardware study [34]. Table V. Shows PV system and inverter costs accounts more than 85% of capital cost for 10 kW proposed system at a specified location.

3.2. Financial Analysis:

Financial analysis involves costs like capital cost, electricity export rate, electricity export escalation rate, inflation rate, project life and debt ratio etc. RETScreen on these inputs generates a detail financial analysis sheet for interested end energy user.

Government of Pakistan offers income tax and premium tariff exemption to support renewable projects [35], so the financial study of the proposed PV system includes no income tax and premium tariff. Considering electricity export rate of 0.055$/kWh [36] for

25 years life span for the project. And electricity escalation rate is considered 6% per annum following its preceding electricity growth rate/pattern in Pakistan. Debt ratio range is suggested by RETScreen, but 50% debt ratio was utilized for financial analysis for a proposed 10 kW PV system project.

Discount rate suggested by RETScreen for North America projects was used to select the discount rate for this project, and 9% was appropriate to value. Table 9. provides input value for the financial assessment of the proposed project. Operation and maintenance cost is considered low due to no moving parts in the system; however, dealing with dust at the proposed project location is important to keep its efficiency maintained to an acceptable value. O&M cost for fixed PV system was estimated to 460$ per year. These values and rest of values were carefully chosen after communication with workers in relevant fields.

Project total cost is 7337$, excluding O&M costs. Electricity exported to the grid is 16,832 kWh which earned 1,683$ at the electricity export rate of 0.055 kWh. The annual income/cost and cumulative net present cost of the project is illustrated in Figure. 3 (a) and (b), respectively. This project is financially good as the initial cost is recovered in about five years and investor/end energy users start earning in the following years.

Table 9
Financial inputs for proposed 10 kW PV plant

Project life	**25**
Inflation	9.1
Electricity export rate	0.055$/kWh [36]
Electricity export escalation	6%
Discount rate	9%
Debt ratio	50%
Debt term	7

3.3. Emission Analysis:

RETScreen provides emission analysis for green renewable energy resources and their equivalent GHG emission mitigation potential. Since a number of gases (CO_2, H_2O, NO_x etc.) are released while burning, however, RETScreen provides an equivalent annual amount of CO_2 to total emissions. It is processed by translating emission gases into CO_2 based on their global warming potential [6].

Table 10. provides 10 kW PV system net annual emission drops through its equivalent cases from the environmental point of view. This proposed system is effective since it is equivalent to 1.3 cars & light trucks not used, 2958.7 litres of gasoline not consumed, 16 barrels of crude oil not consumed, 6.9 people reducing energy use by 20%, 1.6 acres of forest absorbing carbon, 0.6 hectares of forest absorbing carbon that could be emitted in case of conventional energy plants and finally equivalent to 2.4 tons of waste recycled. It is important to mention this data varies from location to location even if 10 kW PV system with same specifications is considered as elaborated in Tables 5, 6 and 7 because daily solar radiation and air temperature varies location to location. RETScreen suggests annual GHG emissions reduction due to 10 kW PV system at specified location of Multi Gardens is equivalent to roughly 6.9 tons of CO2 with equivalent annual electricity exported to the grid scales to 16,832 kWh.

Table 10
Equivalent Cases Value for proposed 10 kW PV system

Cars & light trucks not used	**1.3**
Litres of gasoline not consumed	2958.7
Barrels of crude oil not consumed	16
People reducing energy use by 20%	6.9
Acres of forest absorbing carbon	1.6
Hectares of forest absorbing carbon	0.6
Tons of waste recycled	2.4
Annual GHG emissions reduction	6.9 tCO_2
Annual electricity exported to the grid	16,832 kWh

3.4. GHG Mitigation Effectiveness in Pakistan's Scenario

Pakistan's three provinces; Sindh [37], Punjab [38] and Baluchistan [39] literature suggests that four kWh of energy can be produced per litre from a 20-kW diesel generator. For the proposed PV system, 16,832 kWh per annum energy is produced through solar radiations in Multi Gardens, which is equivalent to the consumption of 4,208 litres of oil consumption or saving the same amount of oil. For the sake of simplicity, this project in its lifetime will avoid burning of 105,200 litres of oil on a single, end energy user with 10 kW PV installed system. This project can significantly reduce GHG emissions in its lifetime at the user end.

4. Conclusion

A single, end energy user importing energy from fossil fuel such as coal, oil and gas, based main grid to meet its energy demands, is contributing towards GHG emissions, indirectly. This end energy user is invisible to the main grid and shift in its energy source can change the dynamics of the power system role in GHG emissions. The aim of this study was to investigate the pivotal role of single, end energy user in GHG mitigation through its techno-economic analysis using tools like NASA Meteorological Data, MATLAB/Simulink, Helioscope and RETScreen software. This study utilized the real data from energy experts for detail analysis of single user among Pakistan's eleven populous cities. The 10 kW PV system in its 25 years lifetime recovered its 7337$ capital cost in about five years and earned user 1683$ per annum by generating 16,832 kWh energy per annum. The system reduced GHG emissions equivalent to 2.4 tonnes of waste recycled, 16 barrels of crude oil not consumed, and 2958.7 litres of gasoline not consumed. Future work includes the detailed study of electric vehicles charging stations based on PV system to mitigate GHG emissions in the transport sector as well.

5. Declarations

Ethical Approval and Consent to participate:

Not Applicable

Consent for publication:

We, authors allow publisher to publish our work.

Availability of supporting data

NASA Meterological Data is provided by RETScreen Software. Tilt and azimuthal angle data is provided by Helioscope software.

Competing interests:

Authors declare no competing interests

Funding:

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Authors' contributions:

J.A.S conceptualization and approach. W.A literature, methodology, writing, results. M.N literature. M.F.U results and M.A.P.M review and supervision.

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Figures

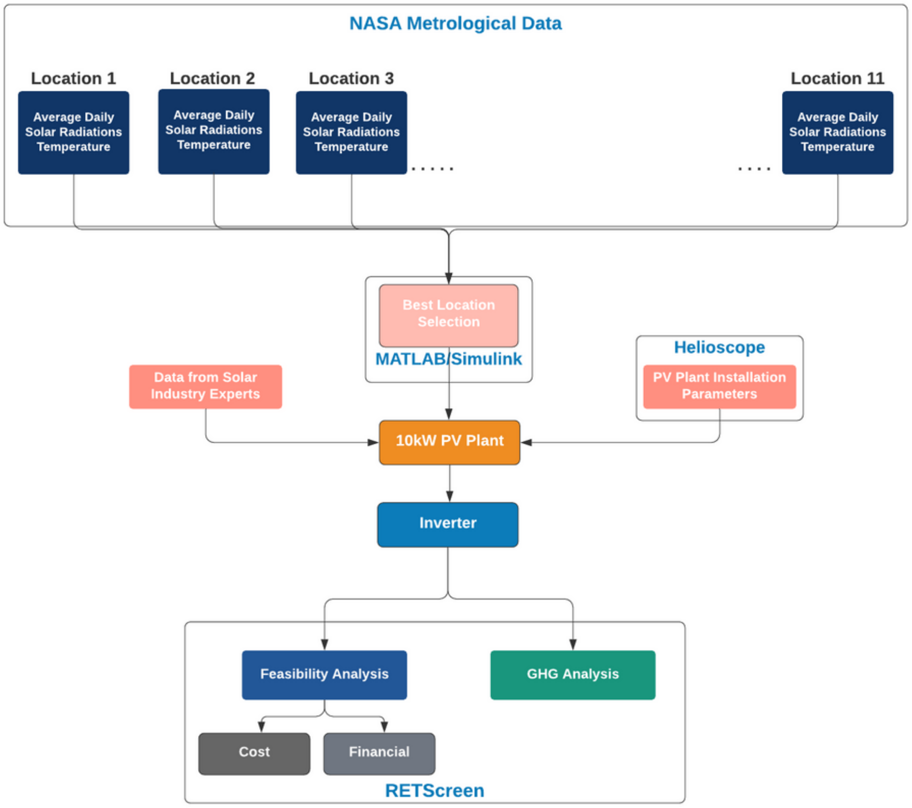

Figure 1

Flow Diagram for Proposed 10kW PV Plant

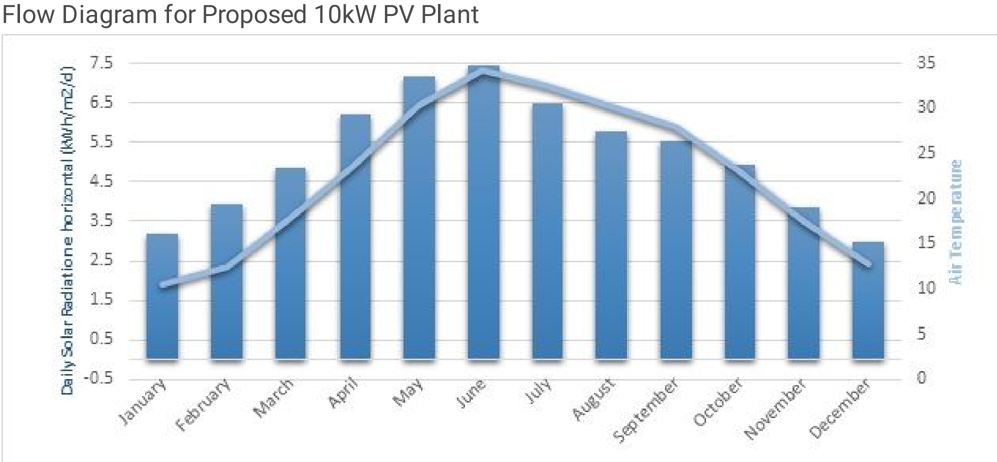

Figure 2

Daily solar radiation and air temperature over a whole year at Multi Gardens.

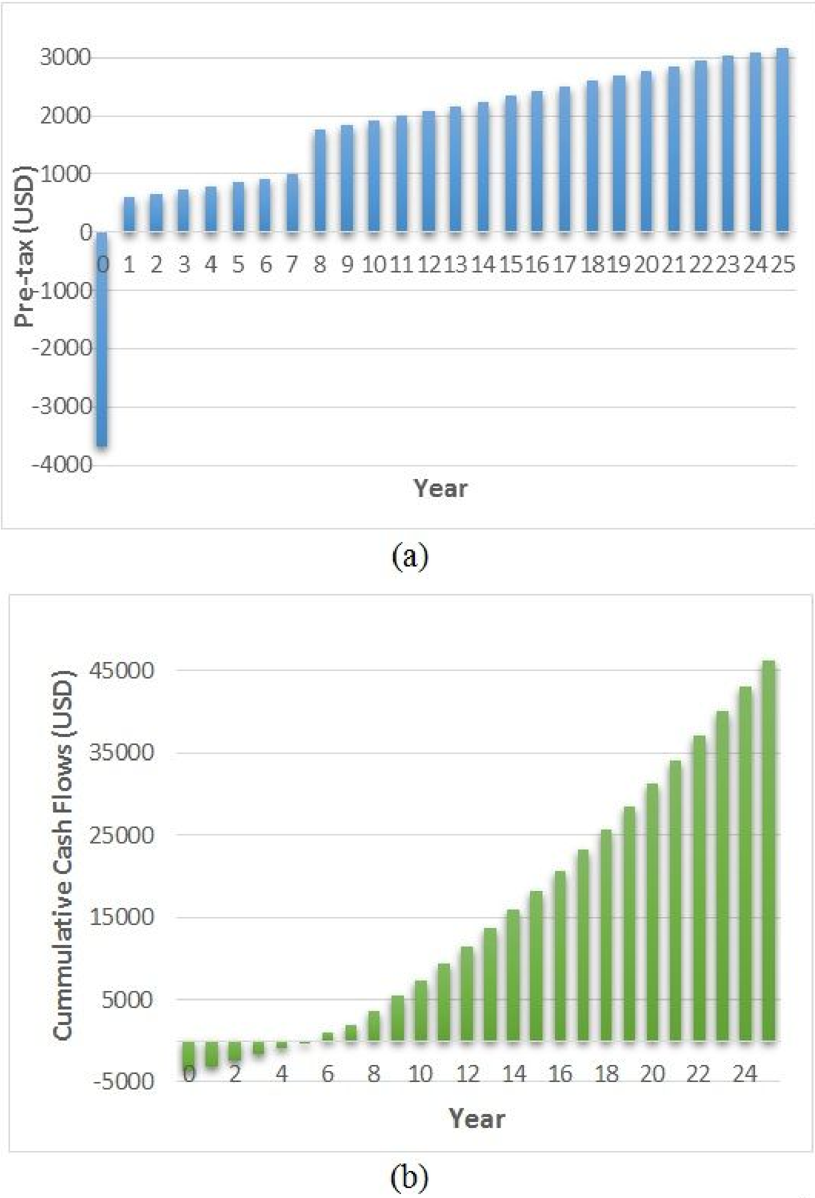

Figure 3

Proposed 10kW system a) Annual income/cost, b) Cumulative net present value